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WATER MOVEMENTS IN THUNDER BAY 1970-73

March 1976

Ontario

Ministry
of the
Environment

The Honourable
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Minister

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Deputy Minister

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WATER MOVEMENTS

IN

THUNDER BAY

1970-73

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INTRODUCTION

The biological study conducted by the Ontario Ministry of the Environment (OME) in the Kaministikwia (Kam) River and Thunder Bay harbour during October 1965 showed accumulations of wood fibre discharged from paper mills, organic enrichment due to untreated domestic wastes and impairment of water quality in the harbour. The lower Kam River, Inner Harbour and the adjacent sections of the Outer Harbour were contaminated by local industrial and municipal waste discharges (OME, 1972). The industrial discharges contributed ninety percent of the oxygen consuming waste inputs (BOD_5) while the bacterial and nutrient contamination eminated from municipal sources. OME (1972) recommended highly controlled discharges in the lower Kam River, Inner and Outer Harbours "to avoid the risk of water quality degradation similar to that which has already occurred in the lower Great Lakes ".

As part of the Upper Lakes Reference Group (ULRG) studies, the OME conducted water movement (Kohli and Palmer, 1974) and water quality (Palmer, 1975) studies in the Thunder Bay region. Kohli and Palmer (1974) recommended further water movements studies in the harbour during the summer months. The present study examines water movement data at three locations in the harbour during winter 1972-73 and summer 1973 (including the results already reported in 1974 for the sake of completeness).

The nearshore currents are known to be complex phenomena. As the water movements in the harbour are temporally variant, it was decided to operate the current instruments in the Inner Harbour (location 143), Outer Harbour (location 144) and offshore of Bear Point (location 142 which is about 9 km north of the harbour entrance). Statistical analysis of the data would provide information on the predominant current directions (if they exist), occurrence of high velocity movements in undesirable directions, net transport, periods of slow or negligible movements, mean speed and persistence factors. The data were also subjected to time series analysis to help understand the physical processes causing the currents.

The Water Pollution Control Board in Thunder Bay presently operates two plants as follows:

	Average Flow		Discharges to
	MIGD	m^3/sec	
North Plant	4.73	0.25	Surface of McIntyre River
South Plant	5.74	0.30	Bottom of Kam River

These two outfalls are to be replaced by a single outfall, as part of the program to upgrade sewage treatment and disposal. Current measurements were continued to find a location in the Thunder Bay region where the natural lake transport and dispersion were the most favourable in terms of minimizing the effects of any discharge on existing water users. The objective of present investigation was to compare data from various locations on a long term statistical basis.

RESULTS AND DISCUSSION

Water Movements in the Harbour

The collected water movement data were smoothed using binominal weights and then divided into monthly records for each study location. Each monthly record was subjected to statistical, time series and dispersion analysis (see Appendix 1). Table 1 presents a statistical summary of water movements at locations 142, 143 and 144. The monthly resultant currents varied from 0.4 to 3.1 cm/sec with persistence factors of 0.14 to 0.91. The resultant current is the net transport vector for a period of record and the persistence factor is a measure of how frequently the water moves in the direction of the resultant. The maximum speeds varied from 8.4 to 28.0 cm/sec while the arithmetic average speeds ranged from 0.5 to 4.3 cm/sec. Sydor (1975) reported maximum current speeds of 15.0 cm/sec offshore of Duluth, Lake Superior which compares favourably with 18.5 cm/sec i.e. the mean of all the monthly maximum speeds for the present study period at all locations. Denek and Saylor (1975) found average speeds of 7 cm/sec in the Inner Bay and 11 cm/sec in the Outer Bay of Saginaw Bay (Lake Huron). These average speeds are much higher than the results of the present study. The present current results are significantly lower (approximately 20 to 50%) than in Lakes Ontario (Kohli and Palmer, 1973) and Erie (Kohli, 1974). The arithmetic mean for all locations studied at Lakeview (Lake Ontario) was 4.6 cm/sec, during 1970-72, whereas for the present study of Thunder Bay it was 2.6 cm/sec or 56% of the Lake Ontario results.

The resultant currents at the Inner and Outer Harbour locations (143 and 144) were going towards the south while the currents near Bear Point (location 142) were generally on shore (Fig. 1). Negligible currents existed for 21 to 45 percent of the time during the summer months at all locations. During the winter months, small currents (less than 0.3 cm/sec) varied from 26 to 79 percent of the time at all locations considered. However, at Bear Point (location 142), the diminutive currents were 59 to 79 percent of the time during winter. The longest period of winter stagnation existed at the Bear Point location. The high percentage of negligible currents during winter months may be partly explained due to an ice cover in the Inner Harbour which started to form by November 30, 1972 and it was a solid sheet in December, 1972 and January, 1973. Similar ice conditions were observed at Bear Point. Water movements in the near shore regions under the partial ice cover have been characterized by longer periods of small velocities (Palmer and Izatt, 1972) than the ice free period.

It may be observed from Table 1 that the results at the Inner and Outer Harbour locations (143 and 144) were very similar and, therefore, the water movements at these two locations were not significantly different. However, the water movements at Bear Point were significantly slower when compared to these harbour locations during November, 1972. The breakwall in the harbour area may be channelizing the water locally so that the velocities here are larger in magnitude than Bear Point currents.

The autospectral analysis of the current data by direction indicates the periodic nature of water movements. The periodicities for the north-south currents range from 1.3 to 12.0 h while for the east-west components they vary from 1.2 to 30.0 h. This differs from the Saginaw Bay study (Danek and Saylor, 1975) which showed no significant periods less than 5 h. Table 2 shows that most of the significant periods are less than 3.5 h. These periodicities are associated with the local harbour geometry. As a result, the primary generating mechanism for currents in the area is related to the harbour geometry. Danek and Saylor (1975) obtained significant periodicities in Saginaw Bay near the inertial period of 17.1 h and the first mode of the free oscillation period in Lake Huron of 10 h. No such comparable periodicities were observed in Thunder Bay.

Some anchor station water quality surveys (sampling at the same location every two or three hours for a day) in 1973 indicated periodicities (Palmer, 1975) of the order of 2 to 4 h for conductivity at the outlet of Kam River. These periodicities are similar to some found in the present study. 12 h periodicity in N-S direction at location 142 during June 1973 is believed to be related to lunar tides. The 30 h period in E-W direction at location 143 during November, 1972 is representative of Lake Superior effects on the harbour.

Dispersion Estimates

Dispersion estimates made from the fixed point current meter data assume a spatially homogeneous velocity field with Eulerian measurements of currents reasonably approximating Lagrangian. This assumption is valid for the large Reynolds numbers (1.5×10^4 to 1.6×10^5 using the water depth as the length scale) occurring at the locations surveyed. The one-dimensional 5 h dispersion coefficients were determined from the current records using a Markov chain method developed by Palmer and Izatt (1971) for three locations. Dispersion estimates were made for four monthly periods at three locations (see Table 3) for comparative purposes. The other records could not be handled by the computer technique due to long periods of negligible currents. These estimated dispersion coefficients (Table 3) are considered low when compared to other nearshore areas in the Great Lakes - see Table 4 (Palmer and Izatt (1970), Csanady (1964), Okubo (1967), Kohli and Palmer (1973)). Table 3 shows that the best dispersion occurred when currents came from the north at 143 during November and December 1972 and at 144 during November, 1972. At location 142 the dispersion was best when currents came from north or east. The dispersion coefficients and the advection are small because currents are of small magnitude. High frequencies of negligible and low currents were observed in this study area which would affect the computation. The frequency of imperceptible currents varied from 26 to 79 percent in this investigation compared to 0 to 45 percent observed over a three year period at five locations in Lake Ontario (Kohli and Palmer, 1973).

Figure 2 shows a plot of the mean distances travelled in two days at three locations. An average speed along each of the four major directions was first computed from Markov chain technique (stochastic process). The distance travelled along each direction was then calculated by multiplying the average speed and the time (2 days) considered. These distances were plotted in Figure 2 and the end points joined by a smooth curve. The procedure was repeated at each location.

Outfall Location

The earlier report by Kohli and Palmer, 1974 recommended that the best site for a new outfall would be the location 144 in the Outer Harbour (the farthest from the shore) where relatively better dispersion was found. At locations 143 and 144 the periods of no water movement varied from 21 to 62 percent of any month. In view of the lower dispersion coefficients and high frequency of slow water movements, effluents discharged into the Outer Harbour will not disperse well. Consequently a diffuser designed to increase dilution by initial mixing, particularly during the periods of unfavourable or no movement and to reduce buoyancy, is recommended for the proposed outfall. A multiport diffuser generally increases dilution by 4 to 10 times over a single buoyant discharge (Rawn, 1961). For best results, a diffuser should be oriented in an east-west direction so that the predominantly southerly currents (see Figure 1) are perpendicular to the axis of the diffuser. The observed current characteristics at location 144 were better than at location 143 for a discharge. The estimated dispersion and transport were better at location 144 during November, 1972 (see Figure 2). As discussed in the previous report (Kohli and Palmer, 1974) the best locations for the outfall in order of priority are:

1. Outside the breakwall in the vicinity of location 144 with a diffuser.

2. Inside the breakwall near location 143 but on the south side of the shipping channel, with a diffuser.

3. At the outlet of the Kam River with a diffuser.

Currents at Bear Point

The water movements at this location were generally less than those observed at locations 143 and 144. Resultant currents from all six periods were onshore (see Figure 1). OME Technical Support staff (Lim, 1975) at Thunder Bay Regional Office found low contents of bark in sediment (qualitative observations) samples near Bear Point. They also reported fecal counts of 2 to 4 and coliform bacteria counts of 0 to 2500 for the water intakes at Bear Point and Abitibi Forest Products. These values are within the permissible criteria for public water supplies (OME, 1973). The bark and coliforms may be further investigated by taking regular samples and then cross-correlating the results with water movements to determine their source; cross-correlating bark and coliforms at the intakes with the downwelling conditions to ascertain if these came from surface waters or not.

Conclusions

The currents observed in Thunder Bay during the present study, were predominantly generated by local water level fluctuations and the local shore geometry. Only a few lakewide periodicities were observed. The water movements and dispersion were low in the harbour compared to the results for other nearshore areas on the Lower Great Lakes. Any material discharged in the harbour will be subjected to poor dispersion and transport. Therefore a diffuser designed to increase dilution by initial mixing and to reduce buoyancy, is strongly recommended for sewage outfalls anywhere in the harbour.

From the present and the previous studies, the recommended locations for an outfall in order of priority are:

1. Outside the breakwall in the vicinity of location 144.
2. Inside the breakwall in the vicinity of location 143 just south of the shipping channel.
3. At the outlet of the Kam River.

All the outfalls should be terminated in diffusers and the effluents jetting from the diffuser ports must be so oriented as to intercept the most prevalent current directions. The centre line of the diffuser should be in the east-west direction for both Inner and Outer Harbour locations and in the north-south direction for the outlet of the Kam River.

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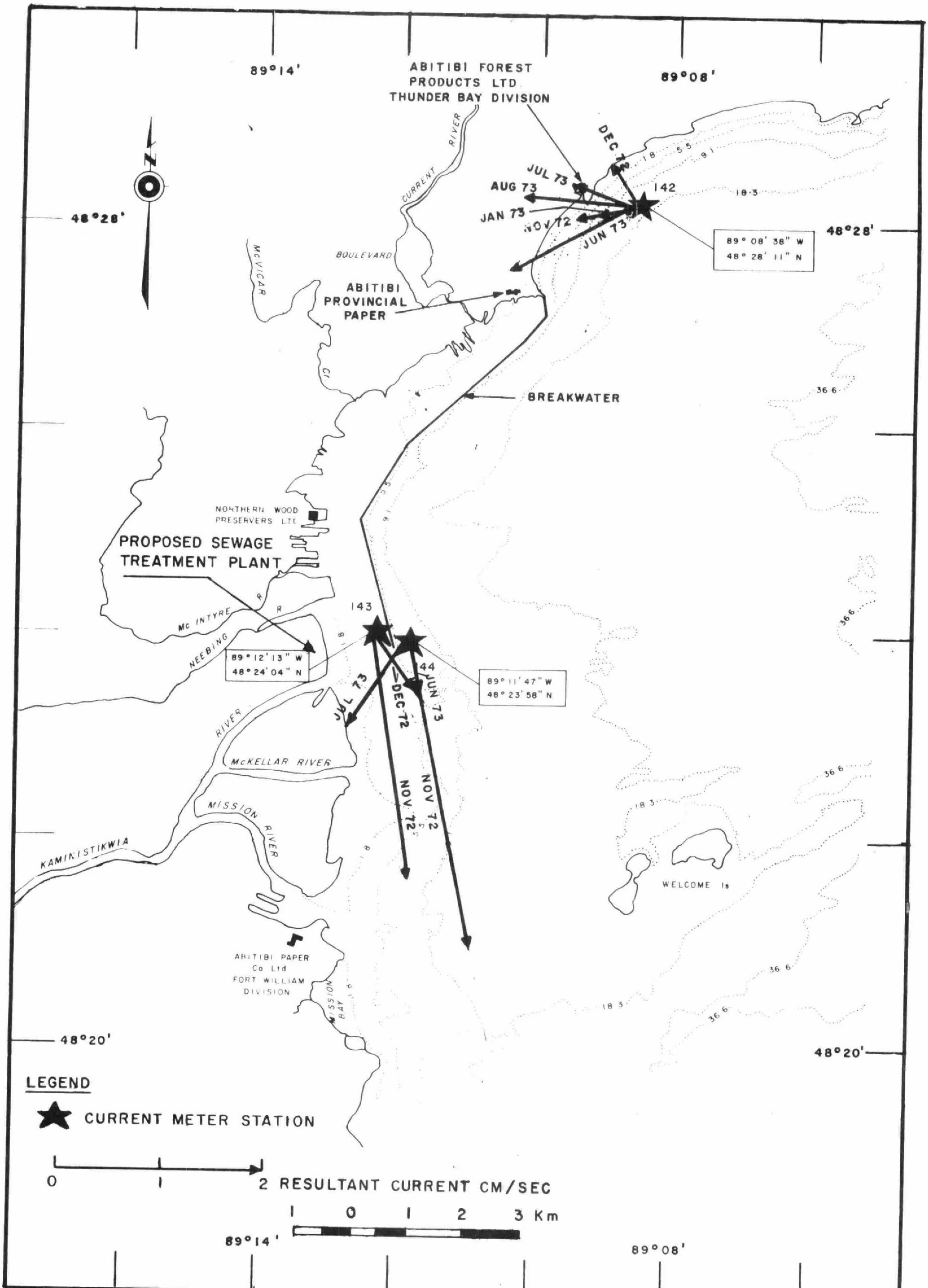

FIGURE 1: RESULTANT CURRENTS, THUNDER BAY

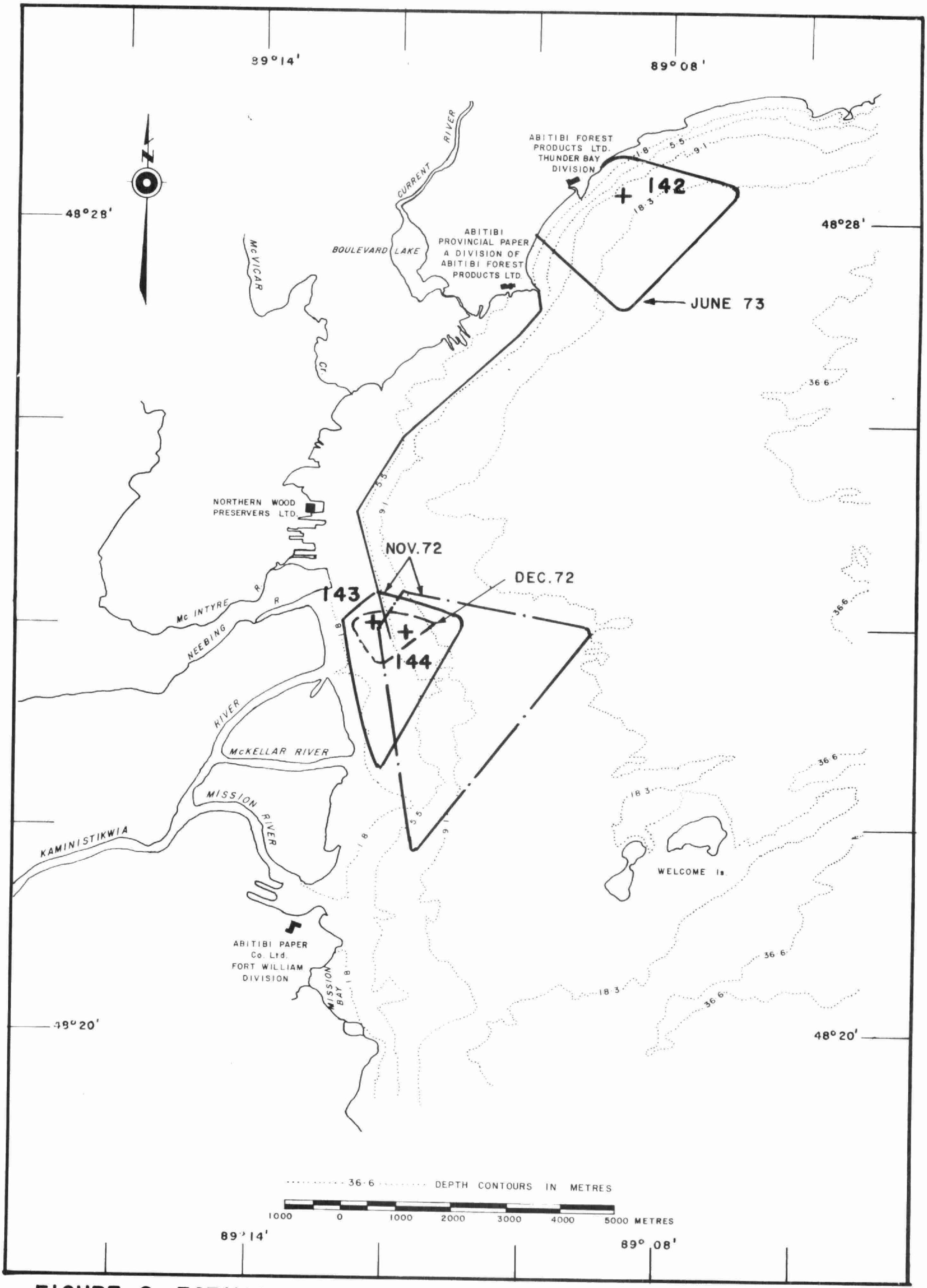

FIGURE 2: ESTIMATED MEAN DISTANCES TRAVELLED IN TWO DAYS
THUNDER BAY

TABLE 1: Summary of Current Meter Results, Thunder Bay

	PERIOD										
	Nov 72			Dec 72		Jan 73	Jun 73		Jul 73		Aug 73
	Location Code										
	142	143	144	142	143	142	142	144	142	144	142
Resultant speed (cm/sec)	0.65	2.54	3.05	0.54	0.81	0.41	1.37	0.59	0.72	1.06	1.17
Resultant direction coming from 0° as North	79	351	348	146	325	73	64	345	109	35	95
Period of velocity <0.31 cm/sec (% of recording period)	62	26	30	59	62	79	45	23	33	21	22
Average speed (cm/sec)	0.98	3.46	4.06	1.06	0.88	0.47	2.42	4.34	2.64	3.55	4.31
Maximum speed (cm/sec)	8.36	22.22	28.01	9.00	10.51	6.30	21.74	27.62	18.04	24.63	27.26
Persistence	0.66	0.74	0.75	0.51	0.92	0.86	0.56	0.14	0.27	0.30	0.27
Total no. of readings	2880	2784	7968	2976	2976	1385	2400	7200	2976	2728	2976
Interval of readings (minutes)	15	15	5	15	15	15	15	5	15	5	15
Percentage of time going in resultant direction	17	45	40	15	29	10	28	21	17	21	19

TABLE 2

Summary of Major Spectral Periods (hours)
80 Percent Confidence Level
Thunder Bay

AUTO SPECTRA OF CURRENTS

Location & Period	North - South	East - West
142 Jun 73	12.0	2.9, 2.5, 2.2
142 Jul 73	3.3, 2.8	None
142 Aug 73	None	4.1, 3.2
143 Nov 72	2.1	30, 2.6
143 Dec 73	None	2.9
144 Nov 72	2.8*, 2.6	3.1*, 2.2
144 Jun 73	6.7, 3.0, 2.1, 1.3	2.4*, 2.1, 1.5, 1.2
144 Jul 73	None	3.0, 1.25

*95% Confidence Level

TABLE 3

5 Hour Dispersion Co-efficient, Thunder Bay

Location & Period	Direction Coming from	Weighted $\sqrt{\overline{y^2}}$	Dispersion Co-efficient ε	Mean Distance	Mean Speed
		m	m^2/sec	m	cm/sec
143 Nov 72	North	71.073	0.140	- 283.35	-1.57
	East	14.915	0.006	- 65.75	-0.37
	South	0.098	0.000	56.16	0.31
	West	9.208	0.002	166.26	0.92
144 Nov 72	North	207.77	1.199	- 416.31	-2.31
	East	20.815	0.012	- 57.81	-0.32
	South	0.459	0.000	78.10	0.43
	West	47.101	0.062	356.63	1.98
143 Dec 72	North	67.427	0.126	- 86.25	-0.48
	East	7.614	0.002	- 41.27	-0.23
	South	0.082	0.000	19.06	0.11
	West	22.351	0.014	106.91	0.59
142 Jun 73	North	102.220	0.290	- 273.97	-1.52
	East	118.496	0.390	- 276.67	-1.54
	South	3.333	0.000	76.23	0.42
	West	2.933	0.000	227.41	1.26

TABLE 4

COMPARISON OF DISPERSION RESULTS

REFERENCE	ε m^2/sec
Present Study, Thunder Bay	0.00 - 1.20
Palmer and Izatt (1970)	0.07 - 17.40
Csanady (1964)	0.04 - 0.20
Okubo (1967)	3.00 - 6.00
Kohli and Palmer (1973)	0.00 - 6.54

APPENDIX 1

WATER MOVEMENT

Method

Recording current instruments were operated at three different locations (142, 143 and 144 - see Figure 1) from November 1972 to January 1973 and from June to September 1973 according to the following schedule.

Location	Instrument Elevation from Bottom	Mean Water Depth	Period of Operation
142	2.4 m	17.4 m	31/10/72 - 14/1/73 5/6 - 6/9/73
143	2.7 m	6.1 m	1/11/72 - 28/1/73
144	3.0 m	7.6 m	31/10 - 28/11/72 5/6 - 10/7/73

No in situ drogue measurements were possible in the winter of 1972-73 due to ice conditions in the harbour.

Data Analysis

The data were processed by months for each instrument location. Two-dimensional frequency of occurrence tables of current magnitude and direction (coming from 0 degree as north) were then determined and tabulated (see Tables 1.01 to 1.11). The results from all instrument locations have been summarized in Table 1 for easy comparison. Monthly resultant currents varied from 0.41 to 3.05 cm/sec with persistence factors of 0.14 to 0.91. The resultant currents at 143 and 144 were going towards the south while at location 142, the currents were onshore during the summer months. Negligible currents (<0.31 cm/sec) recorded from 26 to 79 percent of the time.

Dispersion Estimates

One-dimensional dispersion estimates (for five hours) were computed from the current meter records for the four major compass directions utilizing Markov chain techniques (Palmer and Izatt, 1971) to compare the directional dispersion characteristics. The results are presented in Table 3 which shows significantly better dispersion in the south direction at all locations. These dispersion computations are based on the assumption that currents recorded at one location apply over the nearby region. The validity of this assumption could be checked by cross-correlatng the current records at other neighbouring locations and/or dye dispersion studies. However, it was not possible to validate the assumption by either means in this study. It is probable that the harbour breakwall and the shoreline will cause significant changes in currents and dispersion patterns in regions close to shore. Therefore, the dispersion predictions are considered estimates only. Nevertheless, it is possible to use the results from one location in a comparative sense with similar results analysed in the same manner from another location.

Autrospectra of Currents

Current data were pre-whitened using binomial weighing factors and subjected to time series analysis to determine autospectra coefficients which were then smoothed by Hanning (see Table 2). The purpose of the spectral analysis was to identify the physical mechanisms responsible for the generation of currents at the locations examined by relating observed periodicities with theoretical determined periodicities for the lake, local bays and diurnal associated factors.

TABLE 1.01

LOCATION CODE 142 (Thunder Bay, Lake Superior)

PERIOD: NOVEMBER 1972

LATITUDE $48^{\circ}28'11''$N

LONGITUDE $89^{\circ}08'38''$W

FREQUENCY TABLE

SPEED (CM/SEC.)	DIRECTION COMING FROM (DEGREES)								
	337.50 - 22.49	22.50 - 67.49	67.50 - 112.49	112.50 - 157.49	157.50 - 202.49	202.50 - 247.49	247.50 - 292.49	292.50 - 337.49	ROW SUMS
0.00-0.30	2.19	8.30	9.76	16.46	14.55	3.16	3.26	4.58	62.26
0.31-0.99	0.35	0.83	1.18	1.22	1.15	0.31	0.45	0.14	5.62
1.00-1.99	0.38	3.54	2.26	1.94	1.11	0.24	0.73	0.28	10.49
2.00-2.99	0.52	3.26	1.84	1.56	0.94	0.28	0.42	0.10	8.92
3.00-3.99	0.07	2.26	1.25	1.15	0.52	0.24	0.21	0.03	5.73
4.00-4.99	0.00	1.81	0.52	0.31	0.28	0.14	0.03	0.00	3.09
5.00-8.99	0.00	3.30	0.31	0.21	0.03	0.03	0.00	0.00	3.89
COLUMN SUMS	3.51	23.30	17.12	22.85	18.58	4.41	5.10	5.14	100.00

RESULTANT CURRENT IS 0.65 CM/SEC. AT 79 DEGREES

MEAN CURRENT IS 0.98 CM/SEC.

PERISTENCE IS 0.66

TOTAL NO. READINGS 2880

MAXIMUM CURRENT IS 8.36 CM/SEC.

INTERVAL BETWEEN READINGS = 15.0 MINUTES

INSTRUMENT WAS OPERATED 2.4 M FROM BOTTOM IN 17.4 M OF WATER

TABLE 1.02

LOCATION CODE 143 (Thunder Bay, Lake Superior)

PERIOD: NOV 1972

LATITUDE 48°24'04"N

LONGITUDE 89°12'13"W

FREQUENCY TABLE

SPEED (CM/SEC.)	DIRECTION COMING FROM (DEGREES)								
	337.50 - 22.49	22.50 - 67.49	67.50 - 112.49	112.50 - 157.49	157.50 - 202.49	202.50 - 247.49	247.50 - 292.49	292.50 - 337.49	ROW SUMS
0.00-0.30	8.87	7.47	2.66	1.72	0.04	1.14	1.47	2.73	26.11
0.31-1.99	7.47	3.67	1.37	0.43	0.04	0.50	0.72	2.30	16.50
2.00-3.99	9.41	2.62	1.58	0.29	0.11	0.43	1.04	2.37	17.85
4.00-5.99	11.49	2.62	0.22	0.14	0.07	0.79	1.94	5.10	22.38
6.00-7.99	3.92	0.65	0.07	0.04	0.00	0.18	0.61	1.98	7.44
8.00-9.99	1.94	0.43	0.04	0.04	0.04	0.07	0.43	1.15	4.13
10.00-23.99	1.80	1.01	0.43	0.04	0.00	0.25	0.47	1.51	5.50
COLUMN SUMS	44.90	18.47	6.36	2.70	0.29	3.37	6.63	17.14	100.00

RESULTANT CURRENT IS 2.54 CM/SEC. AT 351 DEGREES

MEAN CURRENT IS 3.46 CM/SEC.

PERISTENCE IS 0.74

TOTAL NO. READINGS 2784

MAXIMUM CURRENT IS 22.22 CM/SEC.

INTERVAL BETWEEN READINGS = 15 MINUTES

INSTRUMENT WAS OPERATED 2.7 M FROM BOTTOM IN 6.1 M OF WATER

TABLE 1.03

LOCATION CODE 144 (Thunder Bay, Lake Superior)
LATITUDE 48°23'58"N
LONGITUDE 89°11'47"W

PERIOD: NOV 1972

FREQUENCY TABLE

	DIRECTION COMING FROM (DEGREES)								
SPEED (CM/SEC.)	337.50 - 22.49	22.50 - 67.49	67.50 - 112.49	112.50 - 157.49	157.50 - 202.49	202.50 - 247.49	247.50 - 292.49	292.50 - 337.49	ROW SUMS
0.00-0.30	16.98	2.71	1.37	0.73	0.01	0.15	1.29	6.96	30.22
0.31-1.99	8.67	0.79	0.39	0.09	0.00	0.31	0.44	2.71	13.40
2.00-3.99	10.71	0.85	0.64	0.16	0.19	0.48	0.84	3.28	17.14
4.00-5.99	10.94	2.50	0.77	0.58	0.05	0.20	0.69	3.00	18.73
6.00-7.99	3.67	0.34	0.21	0.14	0.11	0.05	0.18	1.59	6.28
8.00-9.99	1.29	0.15	0.09	0.04	0.10	0.09	0.08	0.65	2.49
10.00-28.99	3.93	1.10	0.62	0.18	0.18	0.44	0.62	4.81	11.75
COLUMN SUMS	56.19	8.44	4.09	1.91	0.64	1.72	4.13	23.02	100.00

RESULTANT CURRENT IS 3.05 CM/SEC. AT 348 DEGREES

MEAN CURRENT IS 4.06CM/SEC.

PERISTENCE IS 0.75

TOTAL NO. READINGS 7968

MAXIMUM CURRENT IS 28.01 CM/SEC.

INTERVAL BETWEEN READINGS = 5 MINUTES

INSTRUMENT WAS OPERATED 3.0 M FROM BOTTOM IN 7.6 M OF WATER

TABLE 1.04

LOCATION CODE 142 (Thunder Bay, Lake Superior)

LATITUDE 48°28'11"N

LONGITUDE 89°08'38"W

PERIOD: DEC 1972

FREQUENCY TABLE

SPEED (CM/SEC.)	DIRECTION COMING FROM (DEGREES)								
	337.50 - 22.49	22.50 - 67.49	67.50 - 112.49	112.50 - 157.49	157.50 - 202.49	202.50 - 247.49	247.50 - 292.49	292.50 - 337.49	ROW SUMS
0.00-0.30	2.35	7.46	4.91	7.43	11.79	10.28	7.29	7.59	59.11
0.31-0.99	0.07	1.04	1.92	1.51	1.24	0.81	0.54	0.40	7.53
1.00-1.99	0.07	1.28	2.22	1.92	2.35	2.15	0.50	0.27	10.75
2.00-2.99	0.00	0.77	1.01	1.81	2.96	2.28	0.17	0.03	9.04
3.00-3.99	0.00	0.67	0.71	0.74	1.81	1.38	0.07	0.00	5.38
4.00-4.99	0.00	1.51	0.37	0.37	0.97	0.71	0.03	0.00	3.97
5.00-9.99	0.00	1.48	0.94	0.81	0.77	0.20	0.03	0.00	4.23
COLUMN SUMS	2.49	14.21	12.06	14.58	21.91	17.81	8.64	8.30	100.00

RESULTANT CURRENT IS 0.54 CM/SEC. AT 146 DEGREES

MEAN CURRENT IS 1.06 CM/SEC.

PERISTENCE IS 0.51

TOTAL NO. READINGS 2976

MAXIMUM CURRENT IS 9.00 CM/SEC.

INTERVAL BETWEEN READINGS = 15.0 MINUTES

INSTRUMENT WAS OPERATED 2.4 M FROM BOTTOM IN 17.4 M OF WATER

T A B L E 1.05

LOCATION CODE 143 (Thunder Bay, Lake Superior)

LATITUDE 48°24'04"N

LONGITUDE 89°12'13"W

PERIOD: DEC 1972

FREQUENCY TABLE

	DIRECTION COMING FROM (DEGREES)								
SPEED (CM/SEC.)	337.50 - 22.49	22.50 - 67.49	67.50 - 112.49	112.50 - 157.49	157.50 - 202.49	202.50 - 247.49	247.50 - 292.49	292.50 - 337.49	ROW SUMS
0.00-0.30	14.15	10.62	5.14	0.97	0.00	7.12	12.63	11.32	61.96
0.31-0.99	2.39	0.17	0.07	0.00	0.00	0.84	3.56	3.46	10.48
1.00-1.99	2.15	0.10	0.07	0.00	0.00	0.17	3.02	4.67	10.18
2.00-2.99	1.21	0.00	0.00	0.00	0.00	0.07	1.24	4.80	7.32
3.00-3.99	0.71	0.10	0.00	0.00	0.00	0.00	0.77	2.35	3.93
4.00-4.99	1.08	0.07	0.00	0.00	0.00	0.00	0.27	1.41	2.82
5.00-10.99	2.09	0.41	0.00	0.00	0.00	0.00	0.10	0.64	3.23
COLUMN SUMS	23.76	11.46	5.28	0.97	0.00	8.20	21.61	28.67	100.00

RESULTANT CURRENT IS 0.81 CM/SEC. AT 325 DEGREES

MEAN CURRENT IS 0.88 CM/SEC.

PERISTENCE IS 0.92

TOTAL NO. READINGS 2976

MAXIMUM CURRENT IS 10.51 CM/SEC.

INTERVAL BETWEEN READINGS = 15 MINUTES

INSTRUMENT WAS OPERATED 2.7 M FROM BOTTOM IN 6.1 M OF WATER

TABLE 1.06

LOCATION CODE 142 (Thunder Bay, Lake Superior)

PERIOD: JAN 73

LATITUDE 48°28'11"N

LONGITUDE 89°08'38"W

FREQUENCY TABLE

SPEED (CM/SEC.)	DIRECTION COMING FROM (DEGREES)								
	337.50 - 22.49	22.50 - 67.49	67.50 - 112.49	112.50 - 157.49	157.50 - 202.49	202.50 - 247.49	247.50 - 292.49	292.50 - 337.49	ROW SUMS
0.00-0.30	19.28	36.32	6.43	2.09	4.98	1.95	4.91	2.96	78.92
0.31-0.99	0.00	1.44	0.87	1.95	0.36	0.00	0.36	0.14	5.13
1.00-1.99	0.14	2.09	0.58	1.37	0.58	0.00	0.43	0.00	5.20
2.00-2.99	0.00	2.02	1.08	1.08	0.36	0.00	0.00	0.00	4.55
3.00-3.99	0.14	2.24	0.29	1.01	0.14	0.00	0.14	0.00	3.97
4.00-4.99	0.00	0.79	0.29	0.58	0.07	0.00	0.00	0.00	1.73
5.00-6.99	0.00	0.00	0.07	0.43	0.00	0.00	0.00	0.00	0.51
COLUMN SUMS	19.57	44.91	9.60	8.52	6.50	1.95	5.85	3.10	100.00

RESULTANT CURRENT IS 0.41 CM/SEC. AT 73 DEGREES

MEAN CURRENT IS 0.47 CM/SEC.

PERISTENCE IS 0.86

TOTAL NO. READINGS 1385

MAXIMUM CURRENT IS 6.30 CM/SEC.

INTERVAL BETWEEN READINGS = 15.0 MINUTES

INSTRUMENT WAS OPERATED 2.4 M FROM BOTTOM IN 17.4 M OF WATER

TABLE 1.07

LOCATION CODE 142 (Thunder Bay, Lake Superior)
LATITUDE $48^{\circ}28'11''$N
LONGITUDE $89^{\circ}08'38''$W

PERIOD: JUN 1973

FREQUENCY TABLE

SPEED (CM/SEC.)	DIRECTION COMING FROM (DEGREES)								
	337.50 - 22.49	22.50 - 67.49	67.50 - 112.49	112.50 - 157.49	157.50 - 202.49	202.50 - 247.49	247.50 - 292.49	292.50 - 337.49	ROW SUMS
0.00-0.30	0.08	4.96	7.83	11.13	9.75	6.17	3.04	2.12	45.08
0.31-0.199	0.08	1.08	2.38	2.33	3.13	1.88	0.83	0.25	11.96
2.00-3.99	0.29	4.38	3.29	0.96	1.58	2.75	1.79	0.75	15.79
4.00-5.99	0.33	8.83	2.25	0.46	0.50	1.79	1.25	0.67	16.08
6.00-7.99	0.08	4.25	0.63	0.08	0.08	0.21	0.21	0.00	5.54
8.00-9.99	0.00	2.42	0.42	0.00	0.00	0.00	0.00	0.00	2.84
10.00-21.99	0.00	2.29	0.42	0.00	0.00	0.00	0.00	0.00	2.71
COLUMN SUMS	0.86	28.21	17.22	14.96	15.04	12.80	7.12	3.79	100.00

RESULTANT CURRENT IS 1.37 CM/SEC. AT 64 DEGREES

MEAN CURRENT IS 2.42 CM/SEC.

PERISTENCE IS 0.56

TOTAL NO. READINGS 2400

MAXIMUM CURRENT IS 21.74 CM/SEC.

INTERVAL BETWEEN READINGS = 15 MINUTES

INSTRUMENT WAS OPERATED 2.4 M FROM BOTTOM IN 17.4 M OF WATER

TABLE 1.08

LOCATION CODE 144 (Thunder Bay, Lake Superior)
LATITUDE $48^{\circ}23'58''$N
LONGITUDE $89^{\circ}11'47''$W

PERIOD: JUN 1973

FREQUENCY TABLE

SPEED (CM/SEC.)	DIRECTION COMING FROM (DEGREES) 337.50 - 22.49	22.50 - 67.49	67.50 - 112.49	112.50 - 157.49	157.50 - 202.49	202.50 - 247.49	247.50 - 292.49	292.50 - 337.49	ROW SUMS
0.00-0.30	0.93	3.07	1.94	3.25	1.54	2.50	4.24	5.22	22.69
0.31-1.99	1.20	2.54	1.54	2.26	0.78	1.24	0.83	2.18	12.57
2.00-3.99	2.88	4.67	2.33	1.64	0.75	1.32	0.99	2.94	17.52
4.00-5.99	2.14	5.97	3.97	2.31	1.51	2.00	1.32	4.28	23.50
6.00-7.99	1.76	1.33	0.72	0.93	0.68	0.64	0.42	2.07	8.55
8.00-9.99	0.96	0.38	0.29	0.39	0.27	0.46	0.46	1.75	4.96
10.00-27.99	1.08	0.27	0.60	1.14	1.50	1.95	1.09	2.61	10.24
COLUMN SUMS	10.95	18.23	11.39	11.92	7.03	10.11	9.35	21.05	100.00

RESULTANT CURRENT IS 0.59 CM/SEC. AT 345 DEGREES

MEAN CURRENT IS4.34 CM/SEC.

PERISTENCE IS 0.14

TOTAL NO. READINGS 7200

MAXIMUM CURRENT IS 27.62 CM/SEC.

INTERVAL BETWEEN READINGS = 5 MINUTES

INSTRUMENT WAS OPERATED 3.0 M FROM BOTTOM IN 7.6 M OF WATER

TABLE 1.09

LOCATION CODE 142 (Thunder Bay, Lake Superior)

PERIOD: JUL 1973

LATITUDE 48°28'11"N

LONGITUDE 89°08'38"W

FREQUENCY TABLE

SPEED (CM/SEC.)	DIRECTION COMING FROM (DEGREES)								
	337.50 - 22.49	22.50 - 67.49	67.50 - 112.49	112.50 - 157.49	157.50 - 202.49	202.50 - 247.49	247.50 - 292.49	292.50 - 337.49	ROW SUMS
0.00-0.30	0.54	3.19	4.67	5.78	7.59	7.06	2.92	1.34	33.09
0.31-1.99	0.07	2.59	2.12	1.55	4.20	3.36	1.48	0.50	15.87
2.00-3.99	0.27	3.63	3.76	1.68	2.99	5.51	1.38	0.91	20.13
4.00-5.99	0.47	5.11	4.17	2.45	1.28	3.93	1.48	0.34	19.23
6.00-7.99	0.10	2.79	1.75	0.61	0.20	1.71	0.94	0.00	8.10
8.00-9.99	0.00	1.01	0.60	0.27	0.07	0.27	0.17	0.00	2.39
10.00-18.99	0.00	0.34	0.64	0.07	0.00	0.03	0.13	0.00	1.21
COLUMN SUMS	1.45	18.66	17.71	12.41	16.33	21.87	8.50	3.09	100.00

RESULTANT CURRENT IS 0.72 CM/SEC. AT 109 DEGREES

MEAN CURRENT IS 2.64 CM/SEC.

PERISTENCE IS 0.27

TOTAL NO. READINGS 2976

MAXIMUM CURRENT IS 18.04 CM/SEC.

INTERVAL BETWEEN READINGS = 15 MINUTES

INSTRUMENT WAS OPERATED 2.4 M FROM BOTTOM IN 17.4 M OF WATER

TABLE 1.10

LOCATION CODE 144 (Thunder Bay, Lake Superior)
LATITUDE $48^{\circ}23'58''$N
LONGITUDE $89^{\circ}11'47''$W

PERIOD: JUL 1973

FREQUENCY TABLE

SPEED (CM/SEC.)	DIRECTION COMING FROM (DEGREES)								ROW SUMS
	337.50 - 22.49	22.50 - 67.49	67.50 - 112.49	112.50 - 157.49	157.50 - 202.49	202.50 - 247.49	247.50 - 292.49	292.50 - 337.49	
0.00-0.30	1.91	4.22	3.67	3.08	1.47	1.91	1.43	2.97	20.66
0.31-1.99	0.40	2.46	3.70	3.30	0.48	0.92	0.51	1.54	13.31
2.00-3.99	1.25	4.18	3.92	4.55	1.32	0.62	0.66	2.82	19.32
4.00-5.99	6.01	7.70	3.34	2.49	0.95	1.50	0.95	6.64	29.58
6.00-7.99	1.58	2.05	1.43	2.27	0.18	0.81	0.73	3.67	12.72
8.00-9.99	0.18	0.33	0.59	0.37	0.15	0.18	0.15	0.55	2.50
10.00-25.99	0.00	0.15	0.30	0.62	0.30	0.29	0.15	0.15	1.96
COLUMN SUMS	11.33	21.09	16.95	16.68	4.85	6.23	4.58	18.34	100.00

RESULTANT CURRENT IS 1.06 CM/SEC. AT 35 DEGREES

MEAN CURRENT IS 3.55 CM/SEC.

PERISTENCE IS 0.30

TOTAL NO. READINGS 2728

MAXIMUM CURRENT IS 24.63 CM/SEC.

INTERVAL BETWEEN READINGS = 5 MINUTES

INSTRUMENT WAS OPERATED 3.0 M FROM BOTTOM IN 7.6 M OF WATER

TABLE 1.11

LOCATION CODE 142 (Thunder Bay, Lake Superior)

PERIOD: AUGUST 1973

LATITUDE $48^{o}28'11"N$

LONGITUDE $89^{o}08'38"W$

FREQUENCY TABLE

SPEED (CM/SEC.)	DIRECTION COMING FROM (DEGREES) 337.50 - 22.49	22.50 - 67.49	67.50 - 112.49	112.50 - 157.49	157.50 - 202.49	202.50 - 247.49	247.50 - 292.49	292.50 - 337.49	ROW SUMS
0.00-0.30	0.27	1.34	2.22	2.92	5.61	6.55	2.66	0.91	22.48
0.31-1.99	0.10	1.28	1.28	1.75	1.98	3.43	2.08	0.57	12.47
2.00-3.99	0.07	2.55	2.86	1.38	2.15	5.61	2.76	0.37	17.75
4.00-5.99	0.17	2.99	3.73	1.34	1.34	8.20	3.36	0.71	21.84
6.00-7.99	0.00	2.79	3.16	0.27	0.60	4.27	1.04	0.14	12.27
8.00-9.99	0.00	2.39	1.85	0.14	0.03	0.94	0.14	0.03	5.52
10.00-27.99	0.00	3.86	3.53	0.07	0.00	0.20	0.03	0.00	7.69
COLUMN SUMS	0.61	17.20	18.63	7.87	11.71	29.20	12.04	2.73	100.00

RESULTANT CURRENT IS 1.17 CM/SEC. AT 95 DEGREES

MEAN CURRENT IS 4.31 CM/SEC.

PERISTENCE IS 0.27

TOTAL NO. READINGS 2976

MAXIMUM CURRENT IS 27.27 CM/SEC.

INTERVAL BETWEEN READINGS = 15 MINUTES

INSTRUMENT WAS OPERATED 2.4 M FROM BOTTOM IN 17.4 M OF WATER

REFERENCES

PALMER, M. D. and J. B. Izatt, 1971. Lake Hourly Dispersion Estimates from a Recording Current Meter. J. Geophy. Res. 73 (3). p. 688-693.